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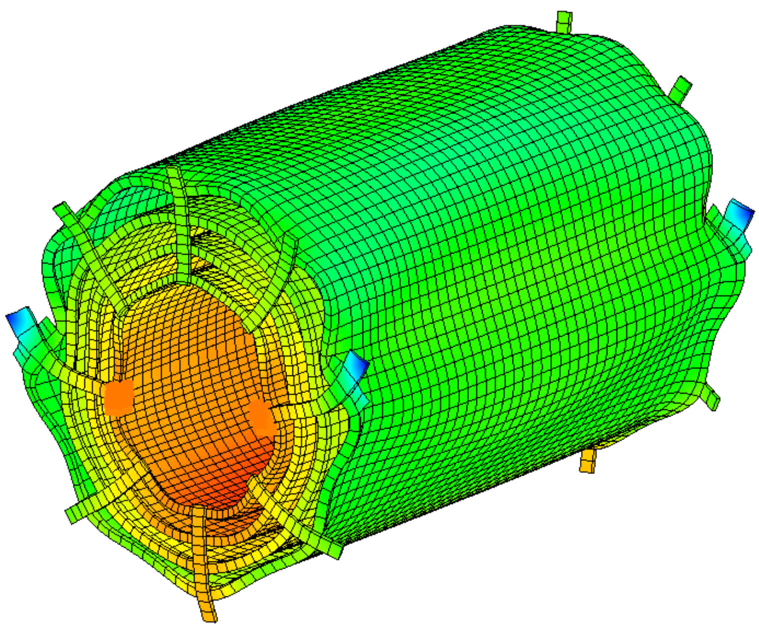
FÉDÉRALE DE LAUSANNE
Laboratoire de Mécanique Appliquée et de Fiabilité

UNIVERSITE
DE GENEVE
Département de Physique Nucléaire et Corpusculaire

ATLAS SCT ASSEMBLY FINITE ELEMENT ANALYSIS



Lausanne, May 30, 2001

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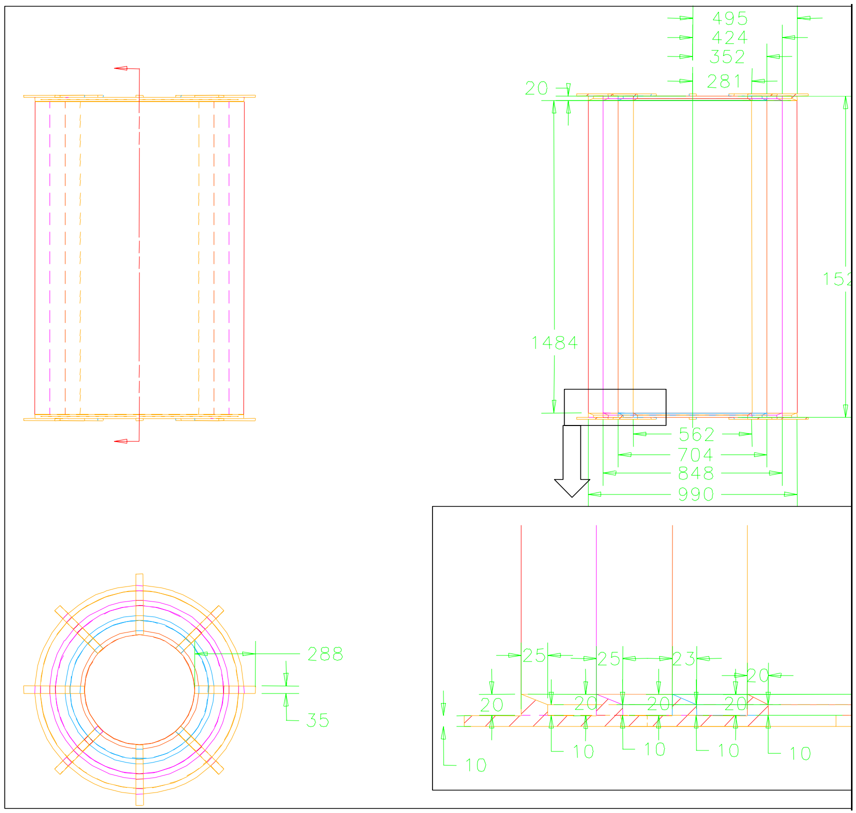
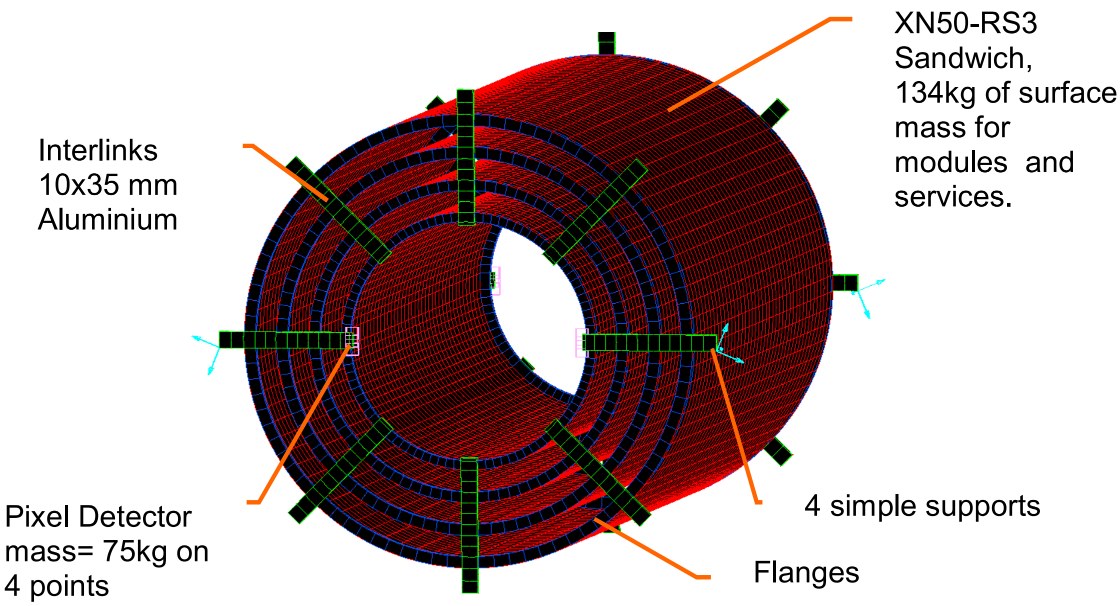
1. Global ATLAS SCT FE Model





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The ATLAS SCT assembly has been modeled by FE method. The geometry of the parts, the assembly specifications and the physical properties have been taken from Atlas SCT specification document and from plans (University of Geneva). Here are the different parts of the assembly and their corresponding data :

1. **SCT Barrels:**
    - Material: XN50/RS3 Honey Comb Sandwich , material properties from the numerical / experimental identification. Material modeled as a Laminate. (Appendix 4)
    - Finite Element Formulation: Serendipian (8 nodes) quadratic FSDT shells (Mindlin formulation, 6 DOF per nodes).
    - Typical element size of about 35 mm.
    - Additional mass for services and modules: 134 kg (total), or 9.04 kg/m^2.
    - First principal material direction oriented along the cylinder axis (Z).
    - Perfectly bounded to flanges in the contact regions.
2. **Flanges:**
    - Material: flanges material properties from the homogenization process , Material modeled as an orthotropic elastic material.. (Appendix 4)
    - Finite Element Formulation: Serendipian (8 nodes) quadratic FSDT shells (Mindlin formulation, 6 DOF per nodes).
    - Typical element size of about 35 mm.
    - No Additional mass, only flange's own weight.
    - First principal material direction oriented along the cylinder circumference .
    - Perfectly bounded to cylinders and interlinks in the contact regions.
3. **Interlinks:**
    - Material / Geometry: because the specifications of interlinks are not already determined at the present time, the interlinks have been modeled as 35x10mm beam in standard aluminum (70Gpa).
    - Finite Element Formulation: 10 nodes quadratic tetrahedrons (3 DOF per nodes).
    - Typical element size of about 35 mm.
    - Aluminum density, no additional mass.
    - First principal material direction oriented along the cylinder circumference .
    - Perfectly bounded to cylinders and interlinks in the contact regions.

The standard boundary conditions of the SCT assembly are the following:

- Simple supports on 4 points at the outer end of the the horizontal interlinks (TRT – SCT supports). (blocked translational DOF, free rotations)
- Supports for Pixel Detector: 4 points at the inner end of the horizontal interlinks. Pixel Detector is modeled by 4 concentrated masses at these support points. Total Pixel Detector weight is estimated to be 75kg in this model.
- Gravity field of 9.81 m/s^2.

The software used for the FEM modeling and solution is SDRC I-Deas Master v8 (Simulation Module). Some calculations have been done for comparison with Abaqus Standard, and as no significant differences where found between the two solvers, we have exclusively used the "I-Deas Model Solution" solver.

2. Study of the initial design of SCT Assembly

The aim of this study is to understand the deformation modes of the SCT assembly in its original configuration, in order to guide us in the future structural optimization study The following conditions are used:

1. **Simulation of SCT without Pixel Detector:**
   - Gravity
   - Distributed mass for Modules and Services
   - Structural Weight.
   - 4 simple supports.
2. **Simulation of SCT with Pixel Detector:**
   - Gravity
   - Distributed mass for Modules and Services
   - Concentrated masses representing the weight of the Pixel Detector.
   - Structural Weight.
   - 4 simple supports.

The resulting displacement fields are shown in the four following figures:

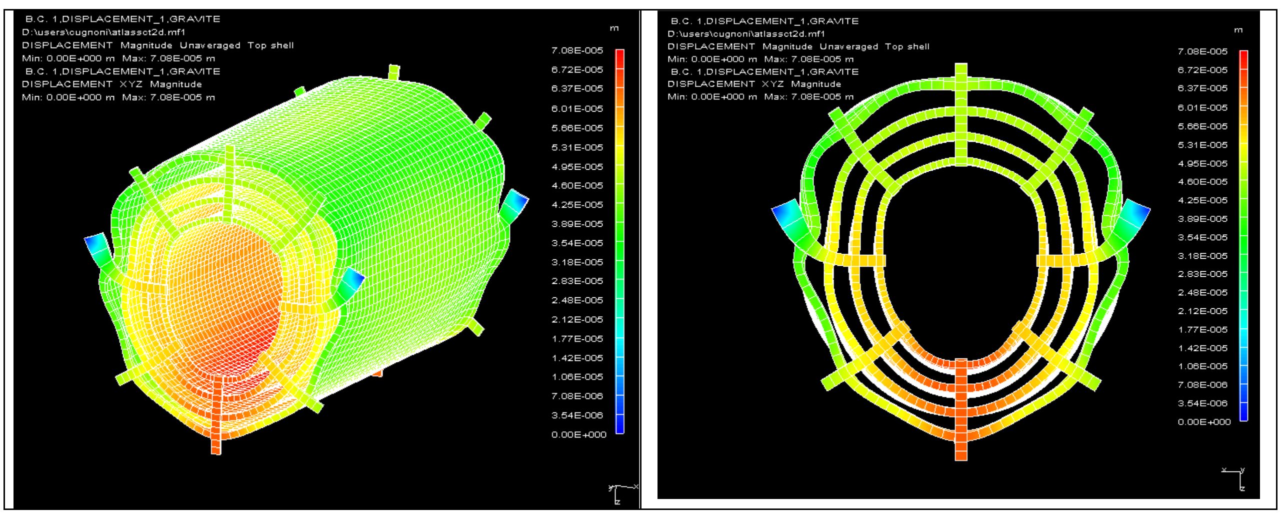


Figure: displacements without Pixel Detector, max = 70 µm

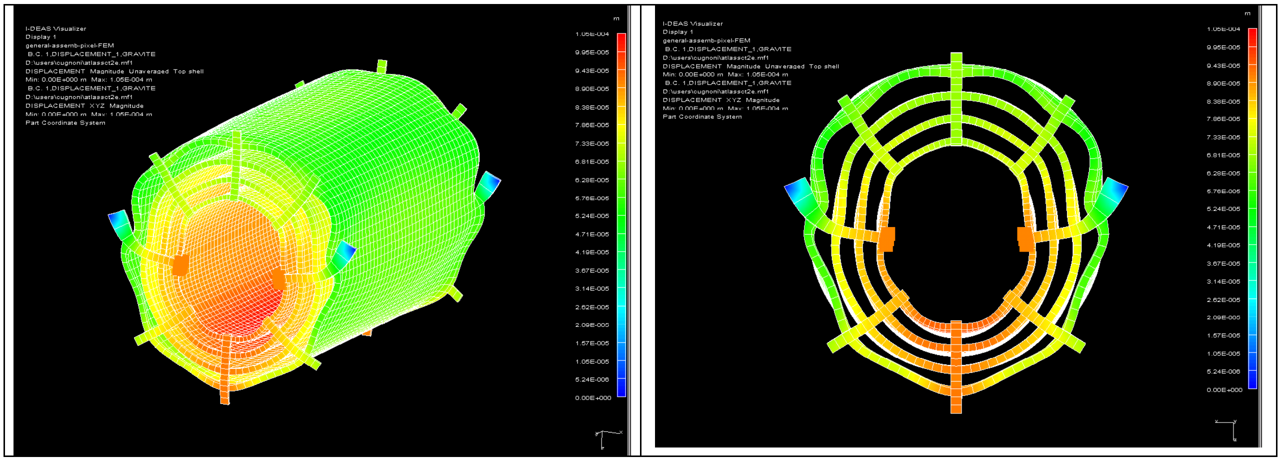


Figure: displacements with Pixel Detector, max = 105 μm

3. Stiffness optimization study of the SCT Assembly

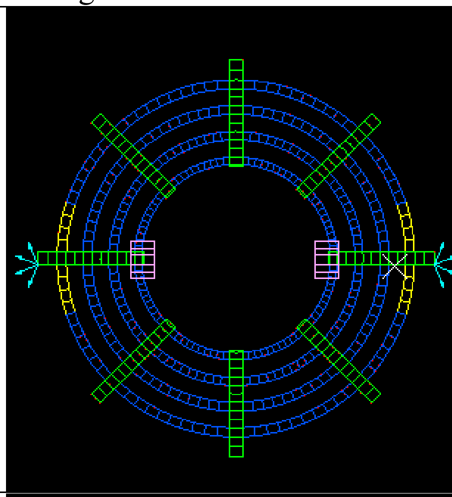
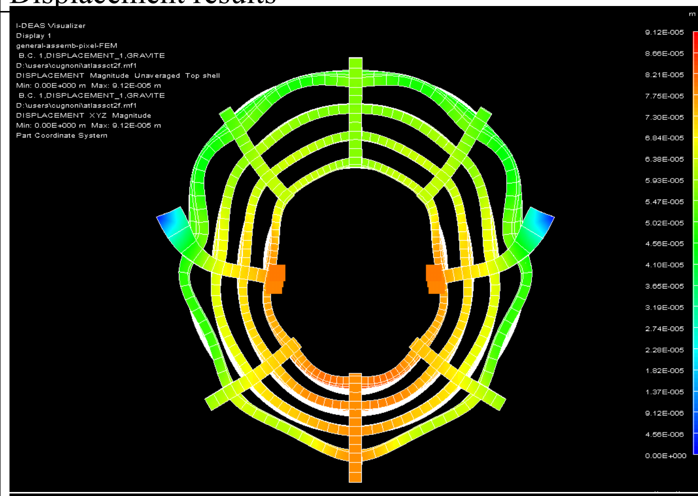
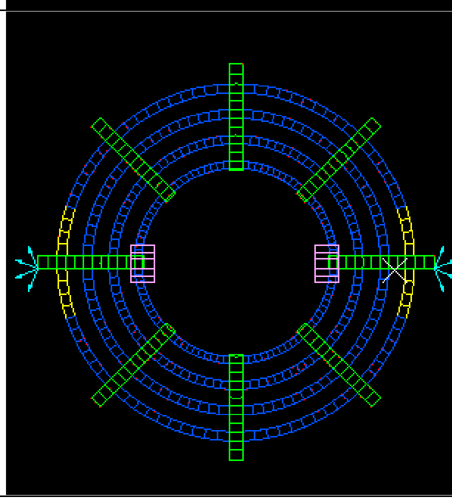
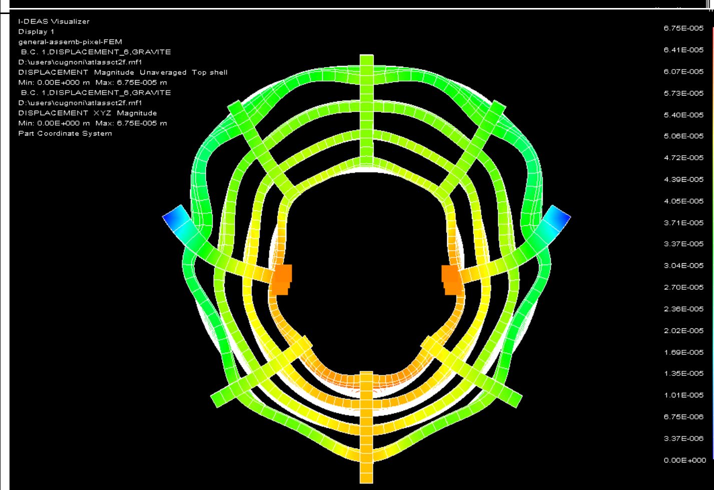
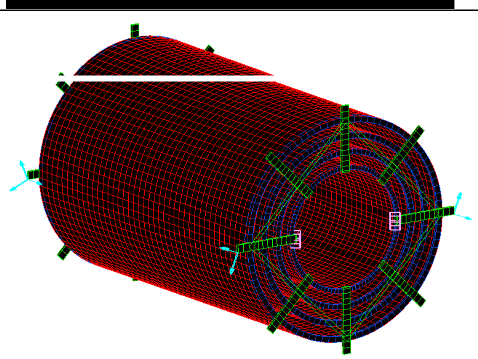
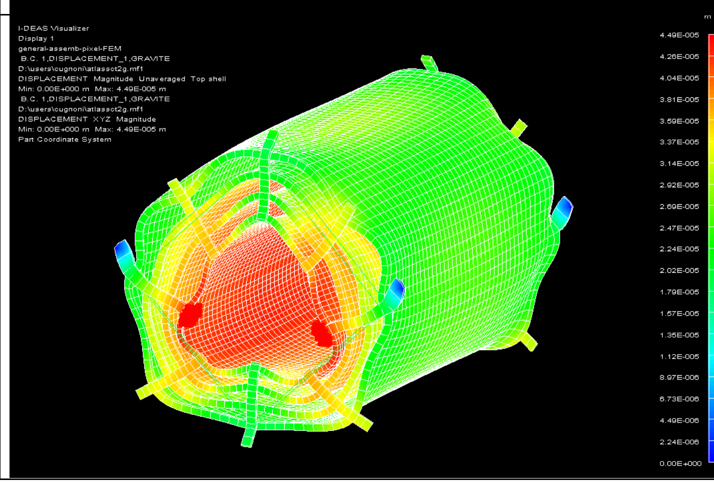
The aim of this study is to analyze the influence of different stiffening methods and to define the optimal method for the reinforcement of the assembly. Different external stiffening methods have been tested, such as infinitely rigid stays (in traction / compression) or external stiffening beams (traction , compression, shear and bending). The effects of the reinforcement of the flanges of barrel 6 or of the stiffness of the interlinks have also been analysed.
All these models use the same material properties and mesh than the preceding ones. The boundary condition are the following (all with Pixel detector included):

- Gravity
- Distributed mass for Modules and Services (134 kg)
- Concentrated masses for Pixel Detector.(75 kg)
- Structural Weight.
- Assembly on 4 simple supports .

The following stiffening techniques have been investigated :

Case	*Stiffening technique*	Maximum Displacement (mm)
1	Barrel 6 Flange Reinforcement	9.12E-02
2	Barrel 6 Flange Reinforcement + Interlink stiffening	6.75E-02
3	Rigid Stays on 4 points	4.49E-02
4	Crossed Rigid Stays	4.92E-02
5	Closed Loop Rigid Stay Design	3.00E-02
6	Reinforcement Elastic Beams	6.50E-02

Simulation Results:

#	Configuration	Displacement results
1		
2		
3		

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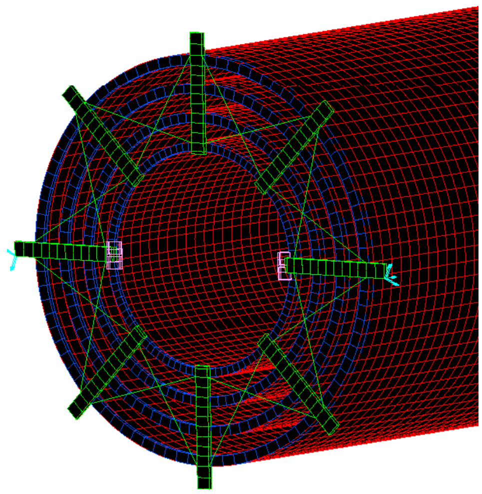

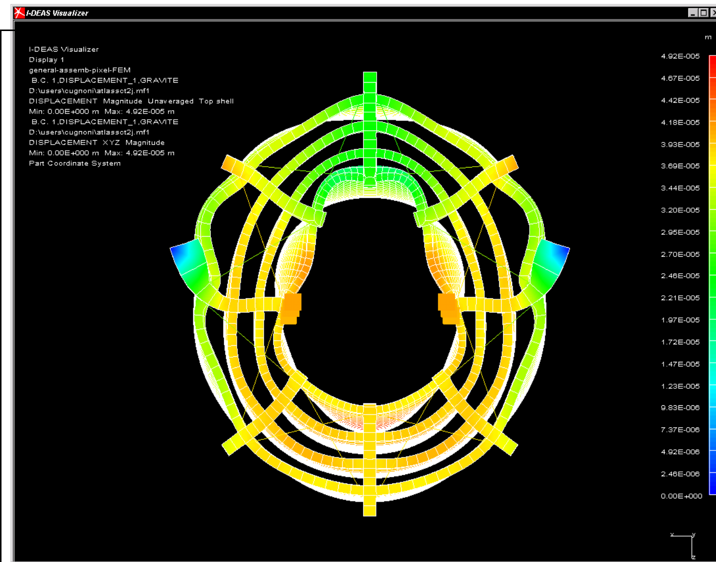
I-DEAS Visualizer
I-DEAS Visualizer
Display 1
general-assemb-pixel-FEM
B.C. 1,DISPLACEMENT_1,GRAVITE
D:\users\cugnoni\atlassct2j.mf1
DISPLACEMENT Magnitude Unaveraged Top shell
Min: 0.00E+000 m Max: 4.92E-005 m
B.C. 1,DISPLACEMENT_1,GRAVITE
D:\users\cugnoni\atlassct2j.mf1
DISPLACEMENT XYZ Magnitude
Min: 0.00E+000 m Max: 4.92E-005 m
Part Coordinate System
m
4.92E-005
4.67E-005
4.42E-005
4.18E-005
3.93E-005
3.69E-005
3.44E-005
3.20E-005
2.95E-005
2.70E-005
2.46E-005
2.21E-005
1.97E-005
1.72E-005
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0.00E+000

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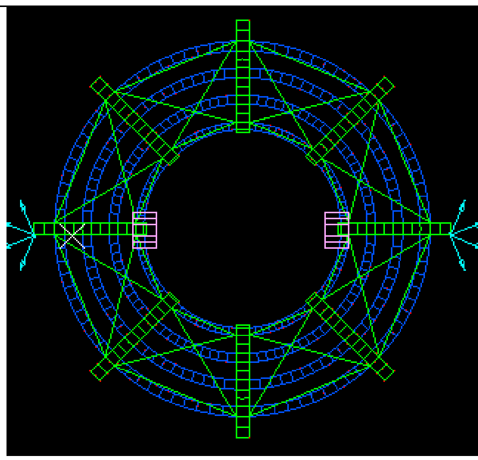

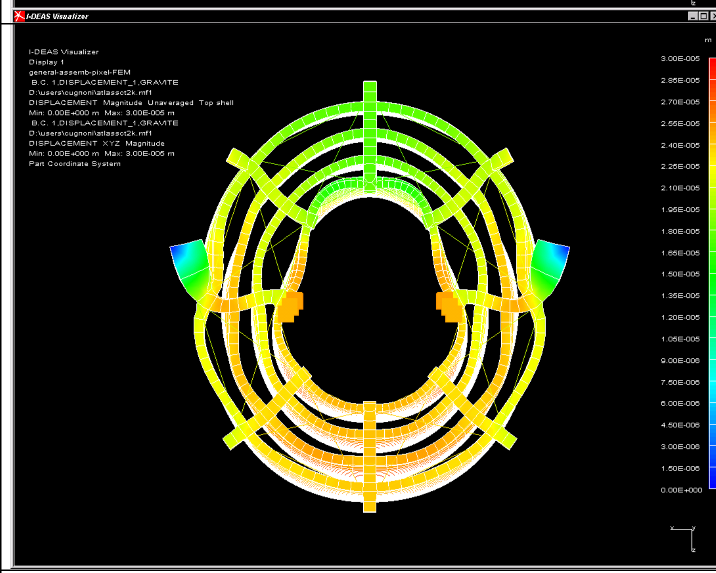
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I-DEAS Visualizer
Display 1
general-assemb-pixel-FEM
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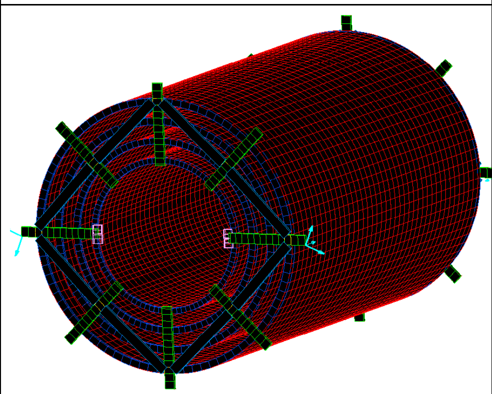
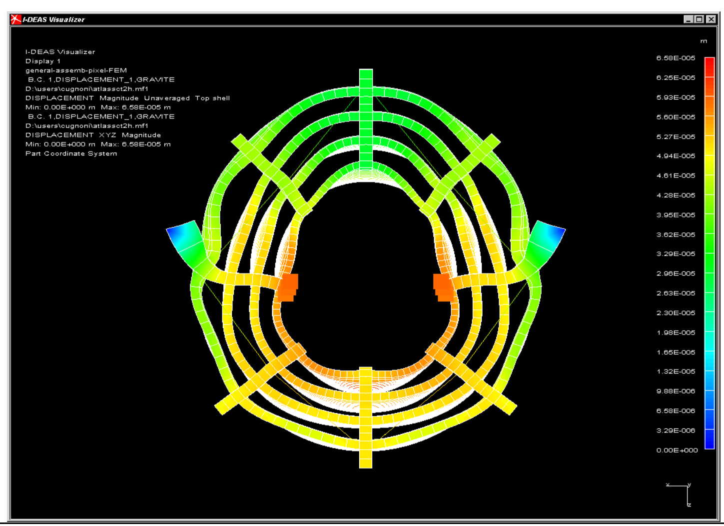
DISPLACEMENT Magnitude Unaveraged Top shell
Min: 0.00E+000 m Max: 3.00E-005 m
B.C. 1,DISPLACEMENT_1,GRAVITE
D:\users\cugnoni\atlassct2k.mf1
DISPLACEMENT XYZ Magnitude
Min: 0.00E+000 m Max: 3.00E-005 m
Part Coordinate System
m
3.00E-005
2.85E-005
2.70E-005
2.55E-005
2.40E-005
2.25E-005
2.10E-005
1.95E-005
1.80E-005
1.65E-005
1.50E-005
1.35E-005
1.20E-005
1.05E-005
9.00E-006
7.50E-006
6.00E-006
4.50E-006
3.00E-006
1.50E-006
0.00E+000

6




I-DEAS Visualizer
I-DEAS Visualizer
Display 1
general-assemb-pixel-FEM
B.C. 1,DISPLACEMENT_1,GRAVITE
D:\users\cugnoni\atlassct2h.mf1
DISPLACEMENT Magnitude Unaveraged Top shell
Min: 0.00E+000 m Max: 6.58E-005 m
B.C. 1,DISPLACEMENT_1,GRAVITE
D:\users\cugnoni\atlassct2h.mf1
DISPLACEMENT XYZ Magnitude
Min: 0.00E+000 m Max: 6.58E-005 m
Part Coordinate System
m
6.58E-005
6.25E-005
5.93E-005
5.60E-005
5.27E-005
4.94E-005
4.61E-005
4.28E-005
3.95E-005
3.62E-005
3.29E-005
2.96E-005
2.63E-005
2.30E-005
1.98E-005
1.65E-005
1.32E-005
9.88E-006
6.58E-006
3.29E-006
0.00E+000

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The first conclusion that we can draw, is that it is difficult to stiffen the structure by using stays without having a lot of local deformation of the cylinders, which can be a problem in practical situations. The simulated stays are considered to be infinitely rigid, a corresponding stiffness could not be reached with real stay, even with large cross sections. The external beam can be a good solution, but the space required by these 35x10mm beams could not be free. As a lot of the displacement is induced by the local deformation and rotation of the interlinks between supports and Barrel 6, a good and applicable solution would be to reinforce the B6 Flanges as well as the outer end of the interlinks.

4. Torsional Behavior of SCT (3 point support)

The aim of this simulation is to predict the maximum deflection of the SCT assembly in the case of a temporary 3 point support (loss of contact of 1 support). The model include the Pixel detector's mass and is essentially the same the standard model : only the boundary conditions have changed from 4 point supports to 3 point support only.

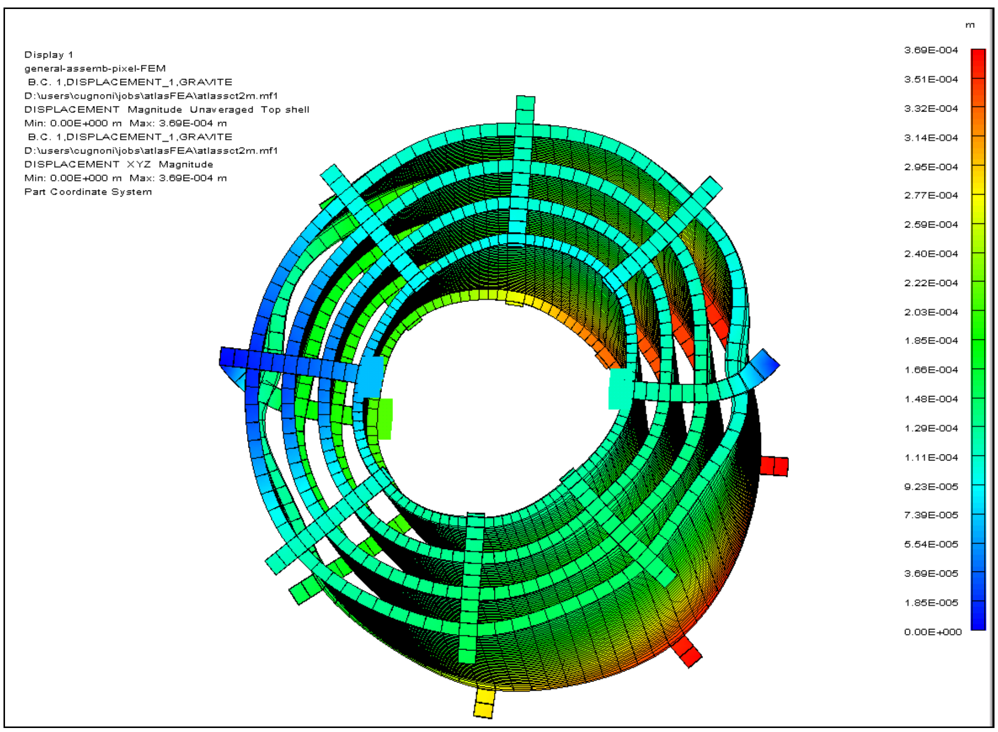


Figure: Deformation of SCT Assembly with temporary 3 point supports. Maximal Deflection (free end of the interlink): 369 microns.

5. Eigen frequencies of the SCT + Pixel Assembly.

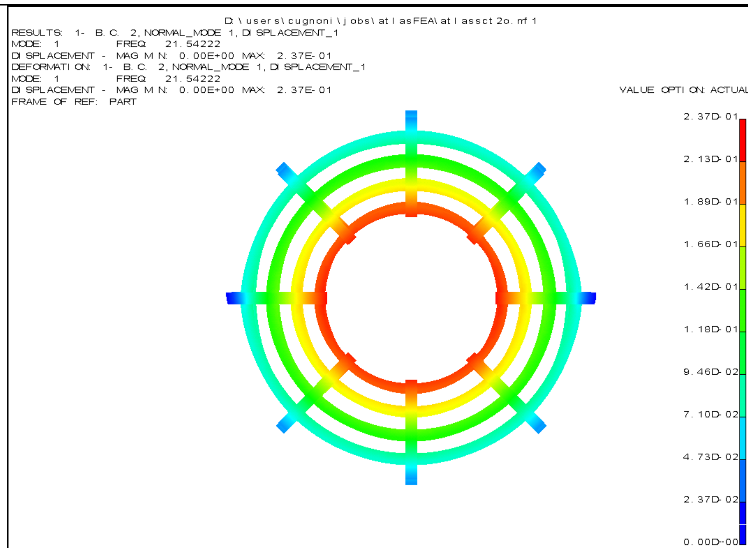
A numerical modal analysis has been carried out in order to estimate the eigen frequencies and eigen modes of the SCT + Pixel assembly. The numerical model is the standard one, which corresponds to the initial design (no reinforcement of the assembly).

Mode	*Eigen Frequencies*
1	21.5 Hz
2	54.4 Hz
3	59.1 Hz
4	60.1 Hz
5	61.9 Hz

The corresponding eigen modes are shown below (amplitude range is unitless, as no excitation is defined):

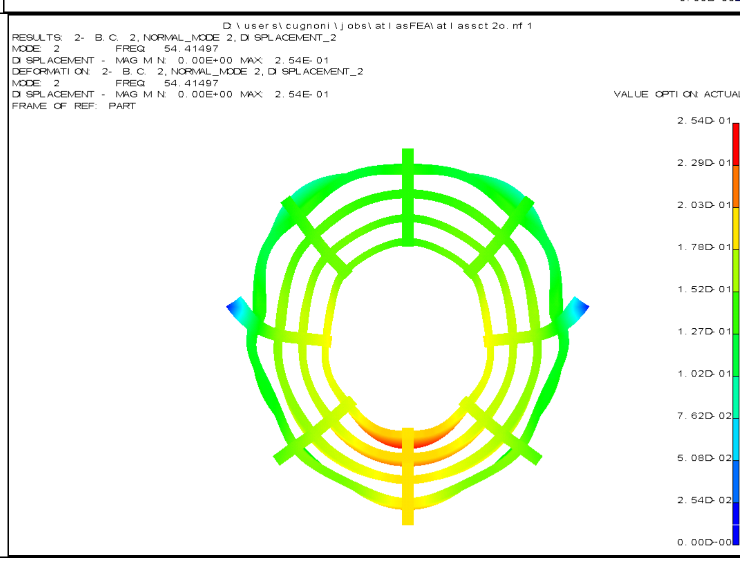
Mode 1:

21.5 Hz



Mode 2:

54.4 Hz



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<td>Mode 3:

59.1 Hz</td>
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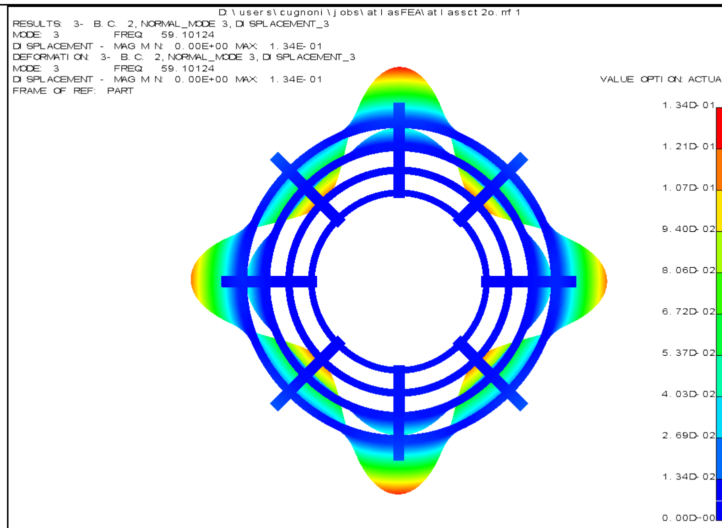
<td>
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<td>Mode 4:

60.1 Hz</td>
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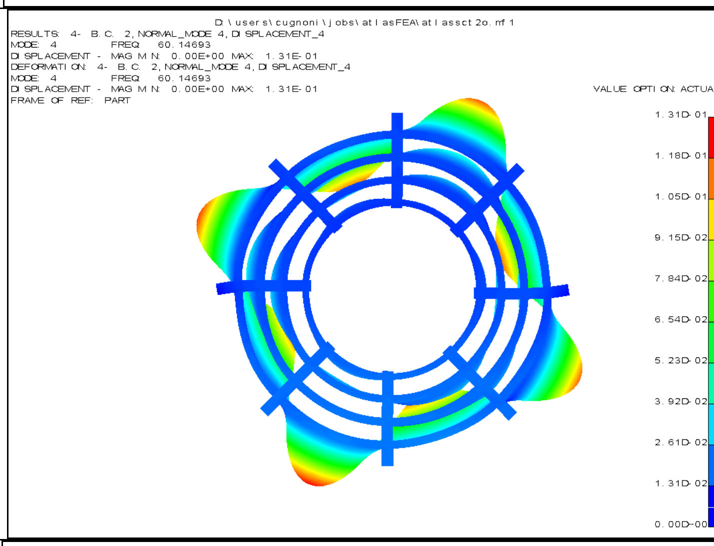
<td>
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<td>Mode 5:

61.9 Hz</td>
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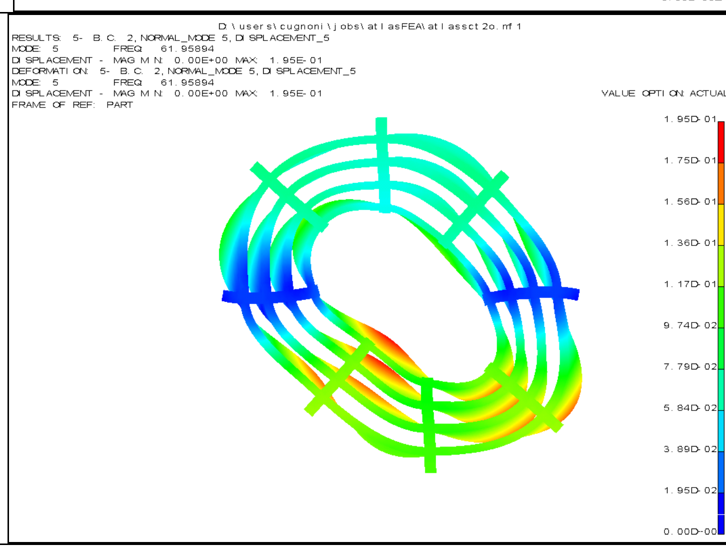
<td>
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6. B6 Flanges and Interlink Reinforcements Study

Following the conclusions of the initial SCT assembly study, we have decided to add a reinforcement to the "B6 flanges to Interlink junction". This reinforcement part has been added to the SCT assembly FE model. This structure has been modeled using a coarse mesh as we are mainly interested in understanding the global deformations modes of the SCT Assembly. The reinforcement part is approximately 105mm long and is made of quasi isotropicXN50-RS3 laminate (2 mm thickness).

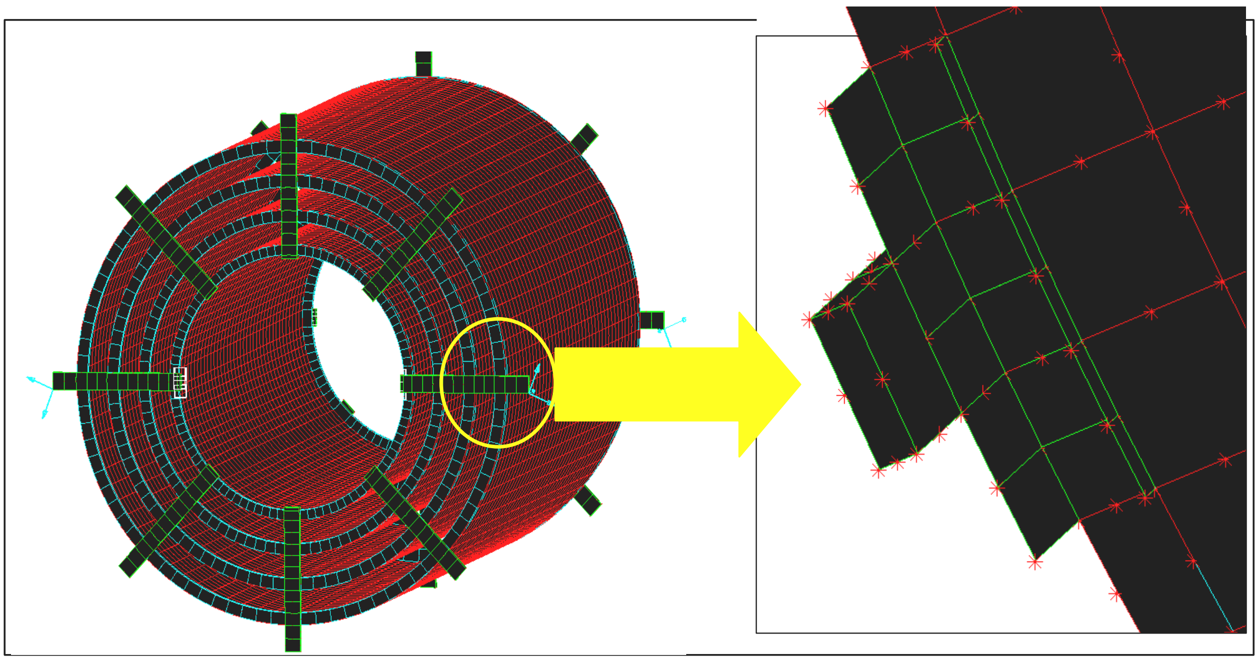
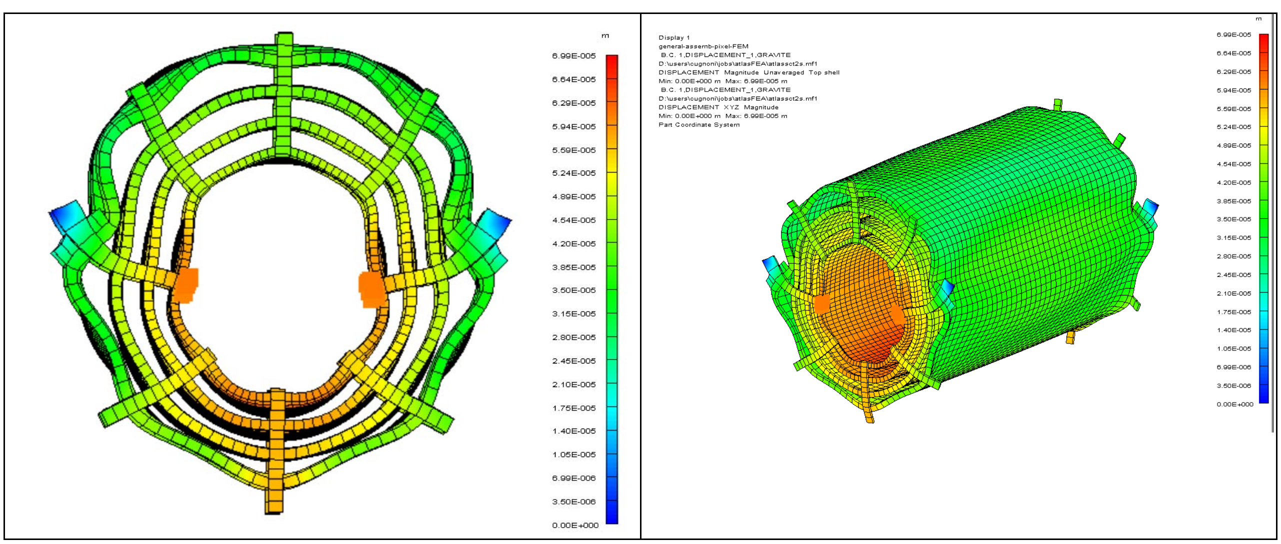


Figure: Barrel 6 flanges to interlinks junction reinforcement part and its FE mesh.

Computation of the displacements of SCT assembly + Pixel (mass) under gravity **with B6 reinforcement part : Maximum deflection of SCT = 69.9 microns.**



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Comparison of max SCT + Pixel displacement for different stiffening techniques:

Case	Stiffening technique	Maximum Displacement (mm)
0	*Original Design, No reinforcement*	1.05E-01
1	Barrel 6 Flange Reinforcement	9.12E-02
2	Barrel 6 Flange Reinforcement + Interlink stiffening	6.75E-02
3	Rigid Stays on 4 points	4.49E-02
4	Crossed Rigid Stays	4.92E-02
5	Closed Loop Rigid Stay Design	3.00E-02
6	Reinforcement Elastic Beams	6.50E-02
7	B6-interlinks reinforcement part	6.99E-02

7. Study of the mechanical effects induced by Pixel Insertion

During the Pixel Detector insertion process, it may be possible that a load could act directly from the end of the pixel insertion tube, thus inducing a global bending of the SCT. This study aims to predict the behavior of the SCT assembly in this case of accidental loading. The pixel insertion tubes and pixel inner tube have been modeled as infinitely rigid beams, so this simulation does not account for pixel tubes deformations. In this case, a 200 N load is applied at the end of the pixel insertion tube (supposed free). This case has been solved without gravity, so the deformation shown in this section represent only the effects of the external load.

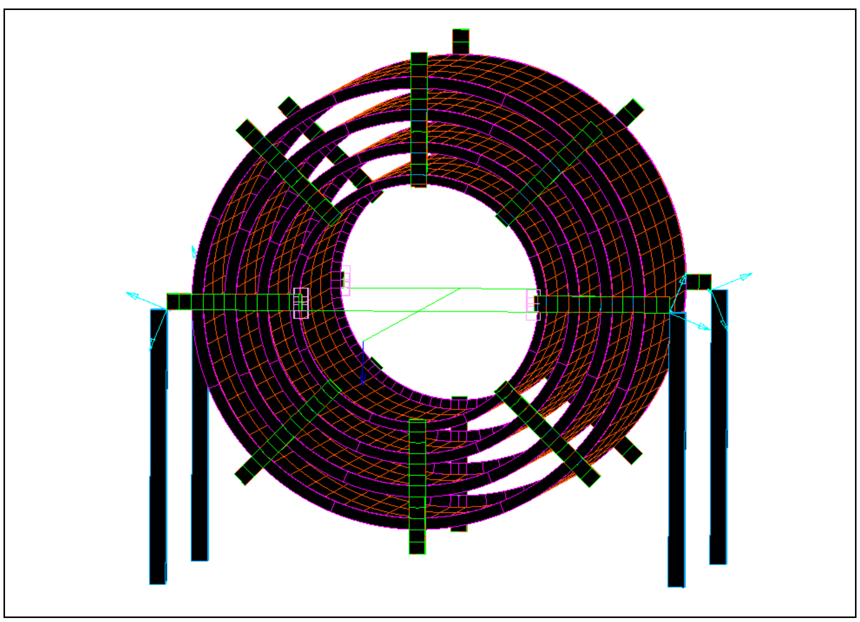


Figure: Finite Element Mesh of SCT + Pixel tubes with external load at the end of Pixel Insertion Tube.

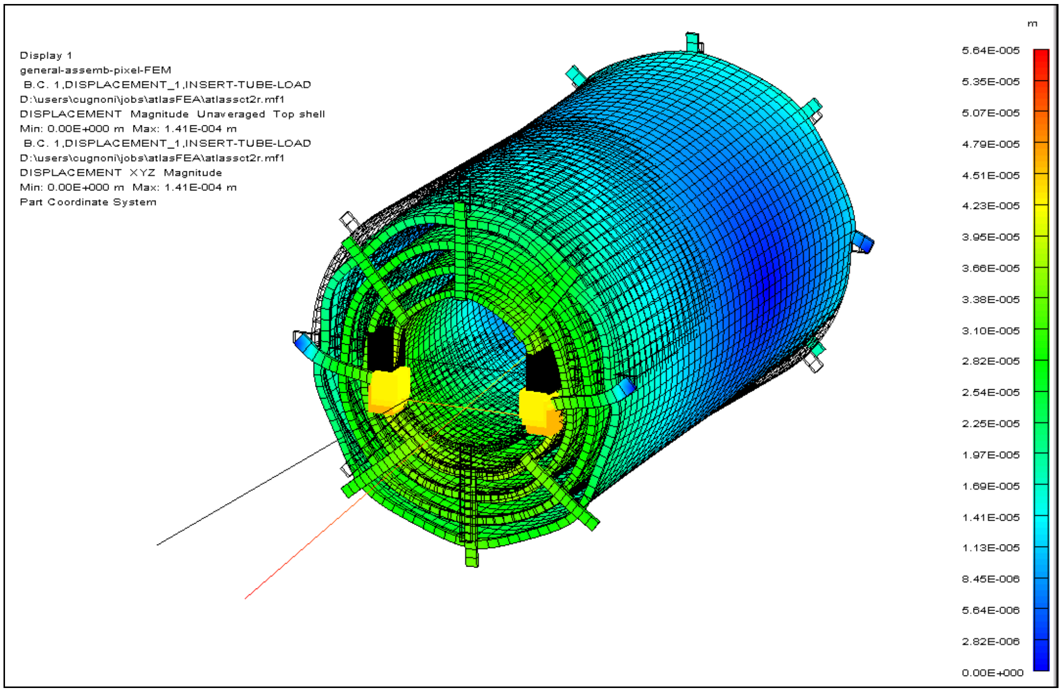


Figure: Deformation mode of the SCT assembly due to an external load at the end of the pixel detector insertion tube.

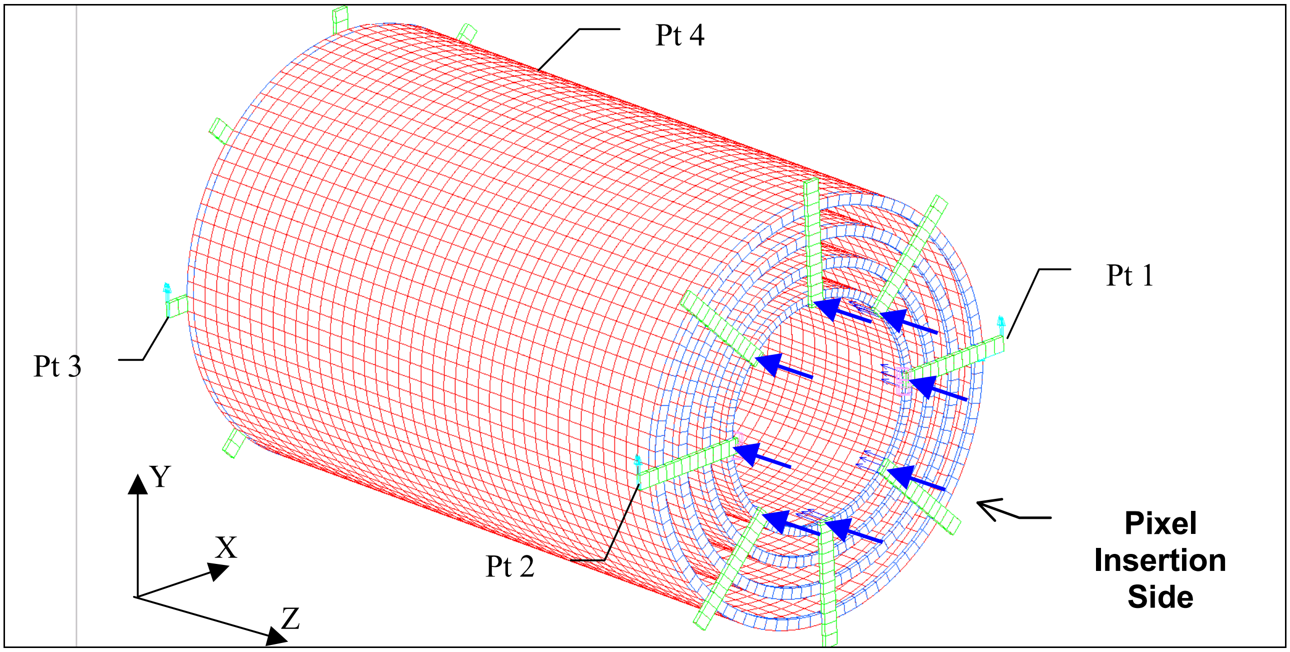
Maximum deflection of the end the insertion tube	***141 microns***
Maximum deflection of SCT structure	***48 microns***

8. Z stiffness of SCT Assembly

We have also calculated the axial (Z axis) stiffness of the SCT assembly. The boundary conditions that have been used are the following:

Point	**Blocked Translational DOF**	**Free Translational DOF**
1	X,Y,Z	
2	Y	X,Z
3	Y	X,Z
4	X,Y	Z

The assembly is loaded in **8 points** with a total axial (Z) load of **200 N.**



The computed displacements are the following:

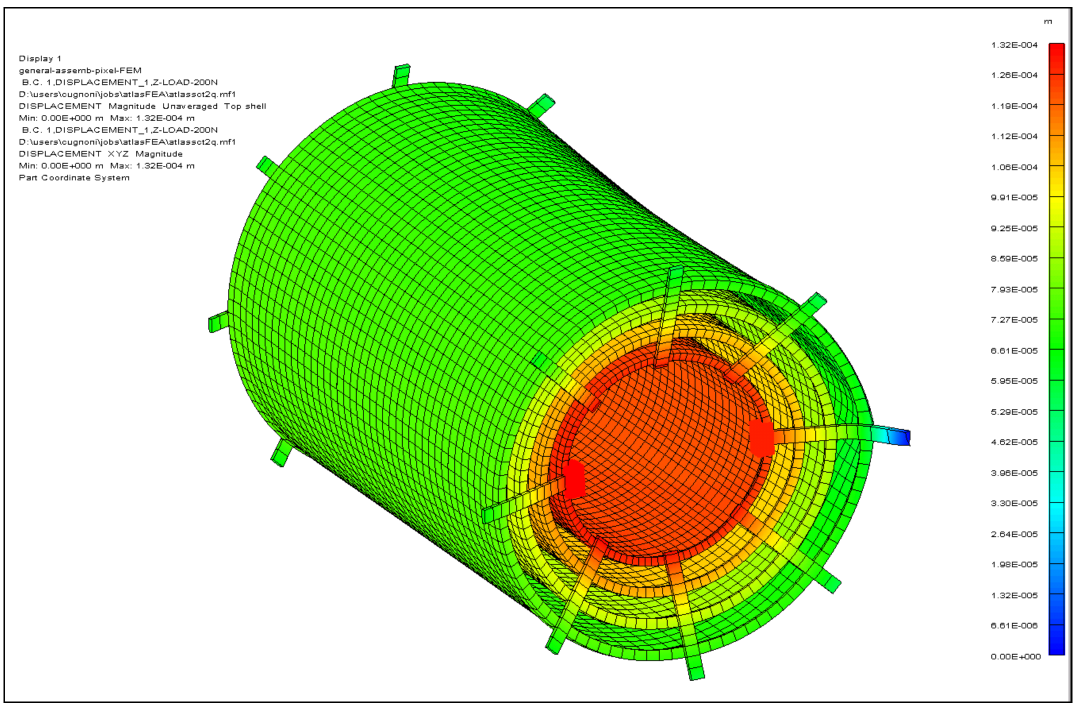


Figure: Displacements induced by a total Z load of 200 N. View form Pixel insertion side.

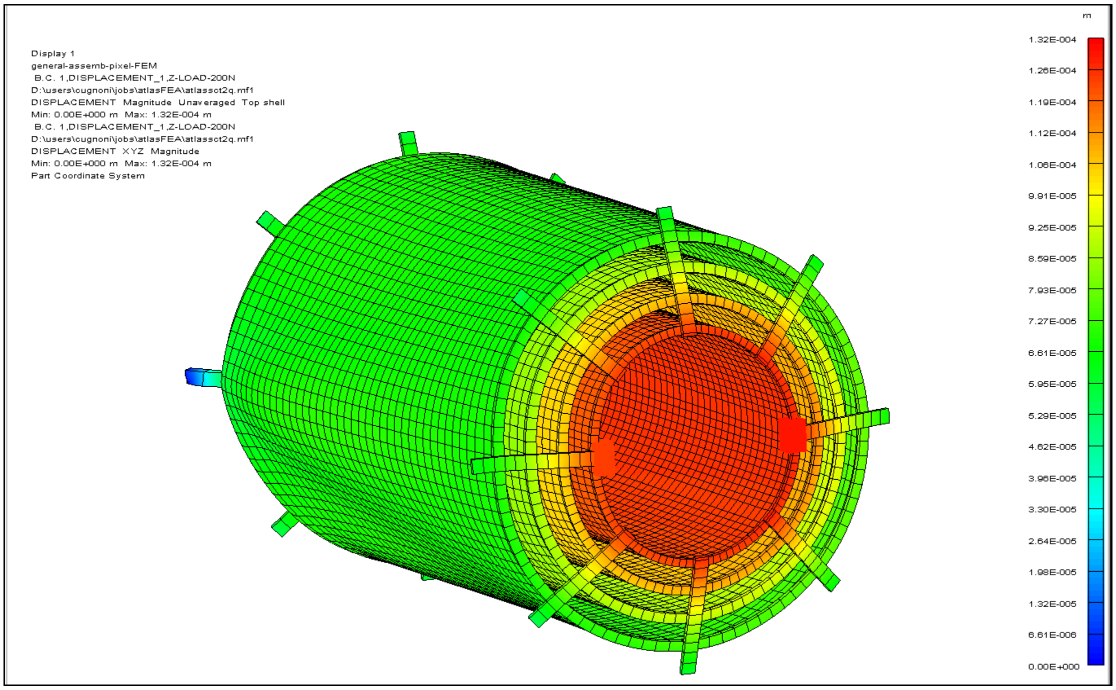


Figure : Displacements, view from the other side.

Axial (Z) apparent stiffness :
Max. Z displacement = 1.32E-04 m
Load = 200 N distributed on 8 points
Equivalent Z stiffness = 1.52E+06 N/m

9. Other Studies:

The following studies are currently in progress :

- Pixel / SCT stiffness coupling study
- Effects of other TRT / SCT interface types
- Displacements during the SCT Assembly Process.

10. Appendix:

Appendix 1. Atlas SCT Assembly : Material properties.

Matériaux

SANDWICH NID-D'ABEILLE XN50RS3

MODELE : LAMINE
Propriétés du laminé homogénéisé
Note: ces propriétés résultent de l'identification avec le cylindre test CASA. Elles représentent donc des valeurs sous estimées des propriétés réelles.
Epaisseur 5.99E-03 m
Densité 3.03E+02 kg/m3

Comportement en membrane

Aij	1 (1)	2 (2)	3 (6)
1 (1)	6.60E+07	2.43E+07	0.00E+00
2 (2)	2.43E+07	6.60E+07	0.00E+00
3 (6)	0.00E+00	0.00E+00	2.15E+07

Comportement en couplage membrane/flexion

Bij	1 (1)	2 (2)	3 (6)
1 (1)	0.00E+00	0.00E+00	0.00E+00
2 (2)	0.00E+00	0.00E+00	0.00E+00
3 (6)	0.00E+00	0.00E+00	0.00E+00

Comportement en flexion

Dij	1 (1)	2 (2)	3 (6)
1 (1)	1.31E+02	4.84E+01	0.00E+00
2 (2)	4.84E+01	1.31E+02	0.00E+00
3 (6)	0.00E+00	0.00E+00	4.28E+01

Comportement en cisaillement transverse (sans correction)

Dij	1 (4)	2 (5)
1 (1)	1.52E+07	0.00E+00
2 (2)	0.00E+00	3.85E+06

FLASQUES
Matériau orthotrope équivalent

Variable	Module de Young E1	Module de Young E2	Coef Poisson Nu12	Coef Poisson Nu21	Module de Cisaillement 12	Module de Cisaillement 23
Unité	Pa	Pa	-	-	Pa	Pa
Valeur	1.16E+11	1.16E+11	3.24E-01	3.24E-01	4.40E+10	8.48E+09

Module de Cisaillement 31
Pa
8.48E+09

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